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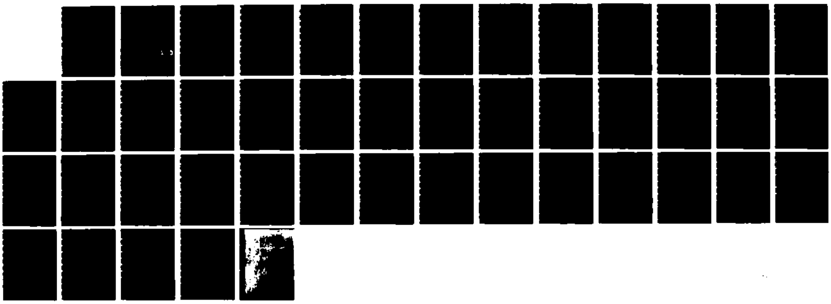

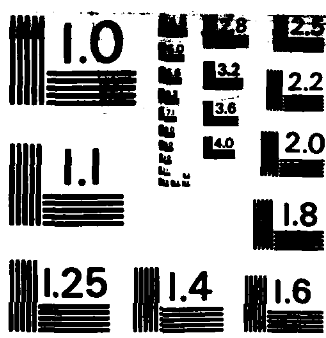
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SPATIAL RESOLUTION THRESHOLDS DURING THE COURSE OF DARK ADAPTATION: An evaluation of the recovery of visual function following failure of optical image intensifiers

PROGRESS REPORT

PERRY SPEROS AND SUNANDA MITRA

FEBRUARY, 1980

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Recovery time to detect sine-wave gratings at five different contrast levels ranging from 10% to 75% contrast was measured at three average target luminance levels corresponding to three night viewing conditions. Five young adult subjects were used in the study. The recovery time was measured after the subject was preadapted to three simulated optical image intensifier luminance levels.

The average recovery time over five subjects was found to be linearly proportional to the log contrast for all frequencies and luminance levels used. (OVER)

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FOREWORD

For the protection of human subjects the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

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Abstract

Because of the many possible permutations of the environmental factors affecting a visual scene a prediction of the resolution tasks that may confront the observer in the field is an extremely difficult task. However, any complex stimulus can be described in terms of its fourier components (vig. sinusoids) and the contrast threshold of a complex waveform is determined only by the amplitude of the fundamental fourier component of its waveform for a wide range of frequencies (Campbell et al, 1968). Therefore by examining the spatial contrast sensitivity function of sine-wave gratings under the viewing conditions confronted by the observer, important information regarding the visual resolution capability of the observer for complex stimuli can be obtained.

In the field, the observer is adapted to the chromaticity and luminance of the optical image intensifier for an indefinite period of time preceding its possible unexpected failure. The visual recovery time is independent of the duration of exposure to the adaptation source when it is longer than a critical time. During the first stage of our project, the critical exposure time to produce adaptation conditions generalizable to indefinitely long exposure durations was determined. This was accomplished by measuring the classical dark adaptation curves following preadaptation to different durations of the conditions simulating the AN/PVS-5 optical image intensifier.

During the second stage, the experimental design for the presentation of sine-wave gratings was developed. The electronically generated sine-wave gratings on the CRT of a high resolution video monitor were found to be the most efficient and versatile method for the presentation of test targets.

Recent studies have demonstrated beyond doubt that the sensitivity of the human visual system to sine-wave gratings is independent of the viewing distance but rather dependent on the visual angle subtended by the test-target up to a critical angle for each spatial frequency (Caronius and Hilz, 1973; Howell and Hess, 1978; Hagemans and Wildt, 1979). For this reason, we have chosen a test-field of visual angle greater than the critical angle for all the spatial frequencies tested during the first set of data collection.

The recovery time to detect sine-wave gratings at five different contrast levels ranging from 10% to 75% contrast was measured at three average target luminance levels corresponding to three night viewing conditions. Five young adult subjects were used in the study. The recovery time was measured after the subject was preadapted to three simulated optical image intensifier luminance levels.

The average recovery time over five subjects was found to be linearly proportional to the log contrast for all frequencies and luminance levels used.

The spatial contrast sensitivity functions expressed in terms of recovery time demonstrate distinct changes in contrast sensitivity with different adaptation luminances as well as target luminances. From these spatial contrast sensitivity function curves, one can predict very clearly the cut-off frequency i.e., the ability to discriminate fine structure at different viewing conditions.

Our next step was to reduce the target size and repeat the procedure at the consequent reduced visual angle of the test-target. We have not completed this stage of the experiment as yet, but the data already taken indicates that the reduction in visual angle results in a lower cut-off frequency, that is the ability to discriminate fine structure is further impaired. Moreover the target luminance level required to detect the gratings is higher for smaller visual angles particularly for higher frequencies.

If time permits, readings for at least three different visual angles of the test field will be taken so that complete information can be obtained regarding the effect of optical image intensifiers on the ability of a user to detect and discriminate any complex visual stimulus at various night viewing conditions.

Introduction

Historically major military operations have been conducted during periods of adequate illumination, e.g. daytime. This is because it is through vision, man's principle sensory modality, that he gathers information from the external world in order to function effectively.

Recently, though, military experiences and modern tactical considerations have placed emphasis on sustained operations with future military deployment. These sustained operations require continuous activity by military personnel extending well into conditions (periods) of darkness. Performance during this period of reduced illumination have placed new physiological and perceptual demands on the human side of the man-machine system. Some military tasks during reduced illumination demand more visual information than the scotopic system (night-time vision) of the visual system can provide.

Man is equipped with a visual system with a dynamic range in response to light which surpases any other known photodetection system. To achieve this sensitivity range some physiological compromises had to be made particularly at lower light levels. Even though, scotopic (night-vision) sensitivity extends down to the detection of a few photons, spatial resolution, color information and temporal processing are severely reduced. THis restricts the capability of the observer to effectively perform his military duty during periods of reduced illumination.

Major technological advances in light amplification have been made during the last 10 years. In particular, the development of th AN/PVS-5 night vision goggle by the U.S. Army Night Vision Laboratory has been offered as an effective interim solution to allow U.S. Army aviators to perform military duties during periods of reduced illumination.

Optical image intensifiers (e.g. AN/PVS-5) serve to aid night vision by amplifying the amount of light reaching the retina. The result is an improvement of the spatial resolving capabilities of the observer employing such a device (Meeteren and Boogaard, 1973). However, since image intensifiers operate by increasing the mean retinal illuminance, they also serve to increase the adaptation level of the operator's visual system. If the device suddenly fails, as they occasionally do without warning or if removal of the goggle is needed, the operator will suddenly find himself visually impaired because of his elevated adaptation level. The time to full recovery of dark-adapted vision may vary from one to three minutes, depending upon the

mean luminance preceding the device failure (Wiley, personal communication). The critical question is, what is the visual capability of the operator at different times during recovery from image intensifier pre-adaptation?

Visual capability is best described as spatial resolution contrast thresholds. In other words, for a given image size, how much contrast is required to resolve it from the background? In the natural world, image size and contrast are not the only parameters, as the gradient of the contrast change must also be considered.

All of the necessary parameters for describing and predicting spatial resolution are embodied in the Visual Modulation Transfer Function (VMTF) (Campbell and Green, 1965). The VMTF is simply the spatial sine-wave contrast sensitivity function, or theoretically, the Fourier transform of the convolution of the optical spread function with the retina-brain spread function (Campbell, 1968). By employing the Fourier transform of any image and using the VMTF, a prediction can be made of the likelihood of the operator's ability to resolve the particular image.

The VMTF is known to change with mean image luminance level (Ness and Bouman, 1967), and therefore, it is anticipated that it will also be dependent on adaptation level. The specific experimental question which must be asked is, what is the shape of the spatial sine-wave contrast sensitivity function at different adaptation levels? These data will provide the basic information needed to describe the resolving capabilities of an observer during the recovery of dark adaptation after the failure of an optical image intensifier. By examining the acceleration of contrast threshold versus adaptation time curves for different spatial frequencies, some statement can be made about which aspects of visual resolution recover the fastest and which recover the slowest.

Optical image intensifiers are an important aid to night vision; however, they operate at the expense of the user's adaptation level. A failure of the device will leave the user visually handicapped for a period of time during which his visual system adapts to the darkened conditions. Important information, which is not now available, is a quantitative estimate of the degree and time course of visual performance impairment in the event of a night vision aid failure.

Because of the many possible permutations in describing the visual environment, a prediction of the resolution tasks that may confront the user in the field is extremely difficult. However, any complex stimulus can be described in terms of its Fourier components (viz. sinusoids). The contrast threshold of a complex waveform is determined solely by the amplitude of the

fundamental Fourier component of its waveform over a wide range of frequencies (Campbell and Robson, 1968).

Therefore, by examining the visual resolution of spatial sine-wave gratings the necessary elementary information for generalization to any stimulus configuration can be obtained.

In the field, the observer will be adapted to the chromaticity and luminance level of the optical image intensifier for an indefinite period of time preceding its unexpected failure. The visual recovery time is independent of the duration of exposure to the adaptation source when it is longer than some critical time.

For the purposes of the proposed study, it would be most efficient to use the shortest adaptation time possible. But, the exposure time should be long enough to produce adaptation conditions generalizable to indefinitely long exposure durations. The purpose of the first set of experiments was to determine the shortest adaptation time which may be used. This was accomplished by measuring classical dark adaptation curves following preadaptation to different durations of the conditions simulating the AN/PVS-5 optical image intensifier. Following the determination of the critical durations, the contrast thresholds for different spatial frequencies will be measured during the period of recovery from adaptation to the simulation of the optical image intensifier. The results of these experiments will provide definitive information about the visual resolution capabilities of an observer during recovery from light adaptation for diffferent viewing conditions. Since sine-wave gratings will be used, the data may be generalizable, by way of Fourier analysis, to any stimulus pattern.

It is the PURPOSE OF THIS PROJECT to examine the acceleration of contrast threshold versus adaptation time curves for different spatial frequencies, thus shedding some light as to which aspects of visual resolution recover the fastest and which recover the slowest.

Previous Work

The development of the Night Vision Goggle (AN/PVS-5) although it is an excellent light amplification device, has brought with it several problems for the individual user. Some of these problems have been the subject of investigation for the past several years by visual scientists (mainly at the U.S. Army Aeromedical Research Lab) and their results are summarized below: Wiley and Holly (1976) report that a comparison of the visual modulation transfer functions of the man-night-vision goggle system vs. unaided normal vision indicated that: (1) under equivalent illuminance levels of under 5% and 25% moon (1.2×10^{-4} ft-L and 6.0×10^{-4} ft-L) performance with the man-night vision goggle system was superior to that of the unaided vision, (2) under full moon equivalent illuminance levels (2.4×10^{-3} ft-L) unaided vision was superior in performance at high spatial frequencies (spatial frequency used varied from 0.1 to 10 cycles/degree) but slightly poorer than the man-goggle system at low frequencies (lower than 8 cycles/degree), (3) under viewing distance of less than 500 feet, depth discrimination with the man-goggle system is equivalent to the unaided photopic vision; (4) under viewing distances greater than 500 feet, depth discrimination with unaided photopic vision is superior to that of the man-goggle system; (5) the stereopsis threshold (using a modified Howard-Dolman apparatus) with the man-goggle system was inferior to that of the unaided binocular vision showing a degradation of stereopsis using the night vision goggle.

The AN/PVS-5 night vision goggles operates by increasing the mean retinal illuminance and thus increases the adaptation level of the user's visual system. If the device suddenly fails as they occassionally do, without prior warning, or if a pilot needs to remove the night vision goggle, he will find himself visually impaired because of his elevated adaptation level. Glick <u>et al</u> (1974) in a preliminary report on the dark adaptation changes associated with the use of the AN/PVS-5 night vision goggle state that the average recovery time that is, time to return to a fully dark-adapted level was two minutes with a range 1.5 to 3 minutes after a five minute pre-adaptation of an equivalent goggle luminance level of 4 ft-L, and equivalent chromaticity level. This relatively rapid recovery to the fully dark-adapted level (2 minutes instead of the normally expected twenty minutes) is attributed to the chromaticity component of the preadaptation source (e.g., the green phosphor used in the AN/PVS-5 night vision goggle). The level of dark adaptation depends upon both the intensity and wavelength of the preadaptation source. Thus, the AN/PVS-5 Night Vision goggle although it does not fully degrade dark adaptation, imposes a visual impairment on the operator for a duration of 2 minutes should it be necessary to remove the goggle or should the goggle fail. It should be pointed out here that these results are restricted to

the chromaticity output of the AN/PVS-5 goggle and are not generalizable to the development of other image intensifiers with a different chromaticity output since the dark adaptation level is a function of the wavelength of the source.

The phosphor used in the AN/PVS-5 night vision goggle has a relatively narrow band output around the green region of the visual spectrum. For this reason, the pilot wearing the goggle will be light-adapted to the chromaticity output of the goggle and therefore his color vision will be altered. Glick and Wiley (1975) compared the performance of the man-night-goggle system vs. unaided vision with a monochromatic red aircraft light on a standard 1:50,000, transverse mercator projectiom map and a black background map (Experimental Map, by the Defense Mapping Agency Topographic Center) designed to overcome the loss of color information. Their results indicated that (1) the black background map does prevent the loss of information when the night-vision goggle (NVG) is used and when the map is viewed with the unaided eye under monochromatic red aircraft map light. This comparison emphasized the importance of available contrast when the NVG is used. The more contrast with the background, the better the aviator's performance would be.

Sanders et al (1975) evaluated the flight performance of pilots during NOE (nap-of-the-earth) flight (without navigation), low level flight and four standard maneuvers using three configurations of the NVG's (40° field-of-view, 60° and 40° field of view with a 30% bifocal cut) and the dark-adapted unaided eye. Their results showed that (1) the 40° goggles were associated with smoother, more gradual control movements than the 60° goggles and the NVG's were associated with slightly lower flight altitudes during the NOE flight segment; (2) the 40° and 40° with a 30% bifocal cut were also associated with a lower mean altitude relative to the unaided eye during the low level flight. This was not true for the 60° goggle and (3)the 40° goggle was favored over the 60° goggle because of the higher resolution angle during the standard maneuvers. Sanders et al (1975) concluded that, in some instances, the NVG's can equip the pilot with increased staying power when flying in intermittent light sources due to their light compensatory capabilites. The unaided eye under the same conditions would be adversely affected because of dark adaptation.

Lees et al (1976) compared aviator performance for terrain flight during Low Level (LL) and Nap of the Earth (NOE) profiles under (1) day flight with the unaided eye; (2) night flight with the unaided eye and (3) night flight using NVG's. They demonstrated that for LL flights, the major factors that discriminated day flights from either night flights or NVG's flights were airspeed related variables and the frequency of small corrective control inputs. It was noted that NVG's flights resemble day flight more than the unaided eye night flight. The

analysis of the NOE flights demonstrated that performance factors measuring severity of roll angles, and the frequency and magnitude of control input, discriminated best among the three visual conditions.

Experimental Design

(A) Apparatus

The experimental design for the presentation of sine-wave grating targets is shown in Figure 1. The test target for the contrast threshold experiments is a sine-wave grating electronically generated on the CRT of a 925 lines high resolution monitor (Conrac) with the aid of a Visual Information Institute, Inc. sync generator model 311 and a pedestal generator 1406. The contrast and frequency of the sine-wave target is controlled by a Tektronix Function generator model FG 504. The presentation of the target is controlled by an electronic switch placed so as to interrupt the video signal to the monitor. The experimenter through the use of this electronic switch controls the duration of presentation of the sine-wave grating. For our experiments a circular field size subtending 15^{o} was used. This was accomplished by placing a circular baffle in front of the CRT of the monitor. The purpose of the baffle was twofold: to set the size of the field to 15^{o} and to eliminate the edges and corners of the CRT from the field of view so that a relatively uniform viewing area could be achieved. The target is centrally fixated by the subject. A centrally fixated 15^{o} target yields dark adaptation curves comparable to those obtained with the test target presented to the peripheral retina. The mean luminance of the target is held constant. This is accomplished by taking photometric measurements using the Spectra-Pritchard photometer (model 1980 A-PL) each time the contrast of the test is changed. The presentation of the target is controlled by the electronic switch. At the same time a pulse activates an electronic timer, thus marking the onset of the sine-wave target. When the subject perceived the test pattern, his task was to press a microswitch which allows an electrical pulse to stop the electronic timer, registering the time it took the subject to see the test target. The response time then is recorded by the experimenter and the time is reset for the next presentation.

The optical system for the preadaptation source is illustrated in Figure 2. A Kodak Model AF2 slide projector (with ABC conversion by Buhl to achieve a uniform field) is used as the light source. Light from the source is passed through a combination of Corning color glass filters (Corning #3-70 and 4-96) simulating the chromaticity output of the image intensifier (AN/PVS-5). The light beam in turn is projected onto a screen. This system is capable of providing a luminance level up to 10 ft-L. The subject views the preadapting field which simulates the size of the viewing field of the image intensifier (AN/PVS-5)

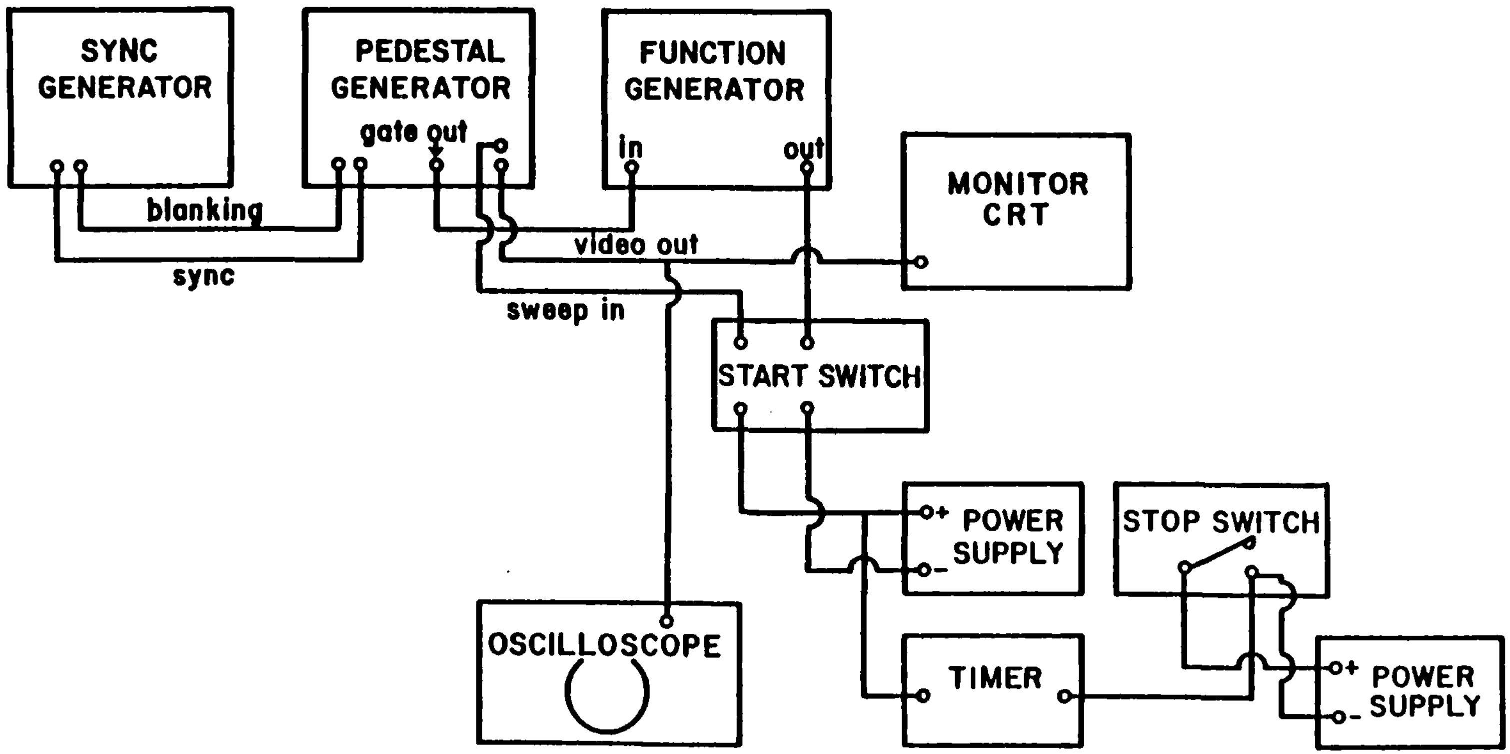

FIGURE 1. Schematic diagram of the experimental set up for sine wave pattern presentation.

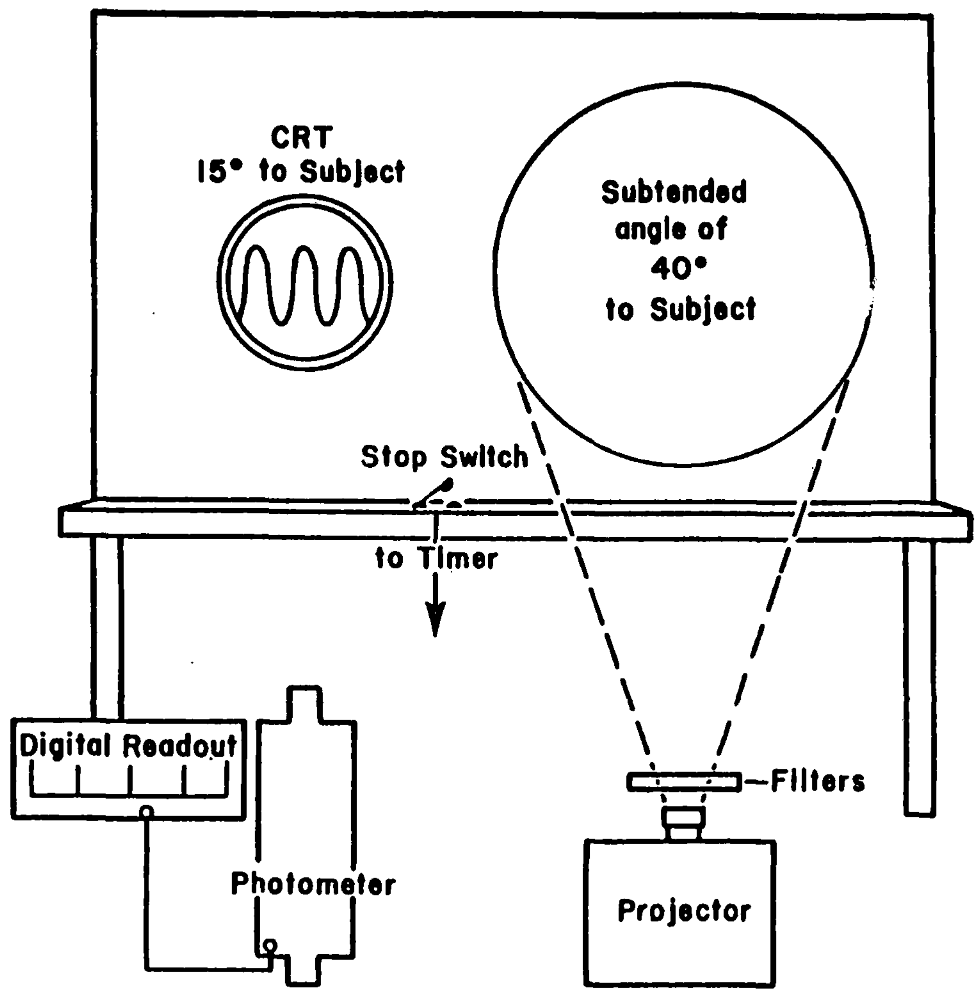

FIGURE 2. Schematic diagram showing the experimental set up for the target and pre-adaptation fields.

e.g., 40° field-of-view. A comparison of the spectral power distribution of the combination of the Corning color filters (obtained by a Curry 14 Spectrophotometer) and the spectral power distribution of the Army Night Vision Laboratory) are shown in Figure 3. This curve represents our best effort after an exhaustive attempt of different combinations of filters. As can be seen in Figure 3, there is a good agreement in the two curves with the exception at the short-end of the spectrum, e.g., at the 440-480 nm region.

(B) Subjects

Five young adults (age 19-25 years) have agreed to participate in the experiments. All subjects have gone through a complete ophthalmological examination including Goldmann visual fields and Goldmann-Weekers dark adaptation curves. All subjects show a minimum visual acuity of 20/20 and normal dark adaptation curves. All subjects have undergone the pilot studies phase of the experiments in order to determine the optimum values for the fixed parameters of the experiments e.g., (1) mean target luminance (2) target exposure time (3) duration of the interval between exposures and (4) range and spacing of contrast values to be used.

(C) Experimental Procedure

The procedure each subject goes through is as follows: the subject is first seated in front of the screen (1 meter away) and (1) is allowed to view the preadaptation field as shown in Figure 2 for a duration of 5 minutes. This duration was found sufficient to fully light-adapt the eye to the luminance and chromaticity output range of an image intensifier (AN/PVS-5). Since the luminance output of an image intensifier is variable from .10 to 10 ft-L, we have chosen three preadapting levels at 0.8, 4, and 10 ft-L, within this range, (2) a set contrast value target (contrast values used: 0.75, 0.45, 0.35, 0.02, 0.10) is presented to the subject immediately after the termination of the preadaptation field, and concurrently the electronic time is triggered. The subject's task is to press a micro-switch when the pattern is first seen. The subject views the target with free fixation. When the subject sees the pattern the session is terminated and the post adaptation time is recorded. The experimenter then records the subject's response time, checks and notes the average field luminance and the same procedure is repeated for 5 sessions. That is, for each frequency and contrast combination five readings are taken. For all five readings the subject is preadapted for 5 minutes and the experimenter checks and notes the average luminance of the field prior to the onset of the session. The average of these five readings is used to calculate the response time of the subjects. The reason for the 5 readings is that the data shows a wide range of variability and this is perhaps true because free fixation is used in order to

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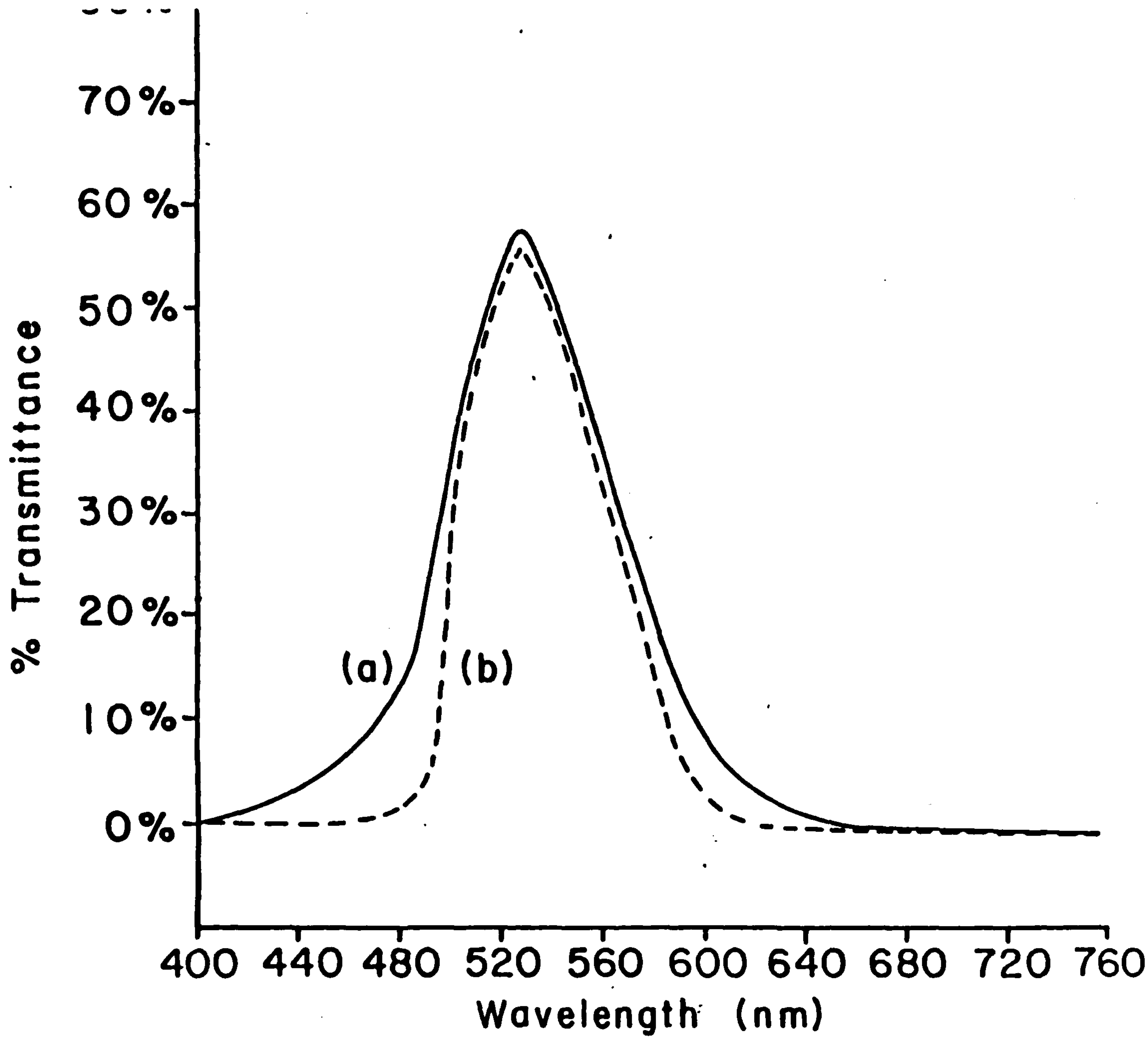

Figure 3 Spectral Power Distribution of (a) AN/PVS-5 Image-intensifier and (b) the combination of colored glass filters simulating the chromaticity of Image-intensifiers used in the preadaptation light source.

simulate pilot conditions. (3) The next lower contrast is set in and step (2) is repeated. The procedure continues until the adaptation time is recorded for 5 contrast values, and (4) the recording of the 5 different spatial frequencies. (.4, 1.0, 2.6, 4.0, 5.6, and 10 cycles/degree).

Since recent studies (Caronius and Hilz, 1973, Howell and Hess, 1978, Hagemans and v.d. Wildt, 1979) have demonstrated beyond doubt that the contrast sensitivity of the visual system for photopic as well as scotopic conditions to sine-wave gratings is independent of viewing distance, but rather dependent on visual angle subtended by the test-target up to a critical angle for each spatial frequency, we have used a test-field (15^{o} visual angle) of much greater than the critical angle for all the spatial frequencies tested during the first set of data collection.

After completion of the first set of the experiment, we have reduced the target size to 2^{o} 30' visual angle at one meter away. The data collection for the second set is not complete yet. We intend to take another set of data at a visual angle of 7^{o} 30' with at least three different target sizes. By so doing, the data can be extrapolated to other possible visual angles subtended by any complex stimulus in the real world.

Data Analysis

The average recovery time for five subjects to detect a circular sine-wave grating of 15^{o} visual angle subtended one meter away is tabulated (Tables I-X) for six spatial frequencies, 0.4, 1.0, 2.6, 4.0, 5.6, and 10.0 cycles per degree for five contrast levels 0.75, 0.45, 0.35, 0.20, 0.10 at three average target luminance, 2.5×10^{-3} ft-L, 6.0×10^{-4} ft-L and 1.2×10^{-4} ft-L.

The average recovery time versus percentage contrast of the gratings plotted on linear graphs for each frequency are shown in Figures 4 to 8. From the characteristic of the curves, it is quite evident that the recovery time if plotted against log contrast would give a linear relationship of slope variable with different luminance combinations.

Based on these findings, next we have plotted the recovery time along linear axis against spatial frequencies along log axis. Figures 9-13 show the resulting curves for combination of preadaptation luminance and target luminance at each contrast level of the sine-wave gratings presented. These curves represent the contrast sensitivity function in terms of recovery time and will be called temporal contrast sensitivity functions.

The temporal contrast sensitivity functions for five different contrast levels indicate that the effect of a chromatic preadaptation of the range used is not significant for target luminance levels of 2.5 $\times 10^{-3}$ ft-L and 6.0 $\times 10^{-4}$ ft-L at contrast above 45%, the recovery time being less than 5 seconds for all spatial frequencies. Only at contrast levels below 35% the degradation in recovery time is somewhat more significant, the longest recovery time being close to 13 seconds. The cutoff value of spatial frequency for 2.5 $\times 10^{-3}$ ft-L target luminance is found to be 15 c/d up to 10% contrast at .8 ft-L preadaptation and drops to 10 c/d for 10 ft-L preadaptation luminance. The cutoff spatial frequency for 6.0 $\times 10^{-4}$ ft-L target luminance is between 5.6 c/d to 10 c/d for all contrast levels.

But the situation changes quite drastically when the target luminance is lowered to 1.2×10^{-4} ft-L. The cut-off frequency now is reduced to only 4 c/d for all contrast and preadaptation levels. The minimum recovery time at this target luminance level is about 17 seconds for 75% contrast and almost 50 seconds for 10% contrast at the highest preadaptation level used (10 ft-L). The longest recovery time ranges between 1 to 2 minutes for different contrast values. The shift in the peak frequency with average target luminance is also noteworthy. The change in contrast does not shift the peak frequency.

Table I
(F_1)
Frequency = 0.4 c/d

CONTRAST VS. AVERAGE RESPONSE TIME
(5 SUBJECTS), 0.4 CYCLES/DEGREE

Preadaptation Lum. in FT-L	Ave Target Lum. in FT-L	Average Response Time in Seconds for Contrast Values				
		0.75	0.45	0.35	0.20	0.10
.8	2.5×10^{-3}	1.55	1.88	2.54	3.25	5.65
.8	6.0×10^{-4}	3.33	5.04	6.37	8.07	12.78
.8	1.2×10^{-4}	10.81	10.49	14.25	18.56	21.33
4.0	2.5×10^{-3}	1.88	2.65	3.96	6.13	9.91
4.0	6.0×10^{-4}	5.64	7.54	9.77	13.03	15.47
4.0	1.2×10^{-4}	12.16	19.57	24.12	34.71	47.35
10	2.5×10^{-3}	2.40	3.82	5.21	7.00	9.55
10	6.0×10^{-4}	6.87	8.83	11.25	15.69	21.01
10	1.2×10^{-4}	19.16	24.42	33.82	46.60	61.37

TABLE II
(F_2)

CONTRAST VS. AVERAGE RESPONSE TIME
(5 SUBJECTS), 1.0 CYCLES/DEGREE

Preadaptation Lum. in FT-L	Ave Target Lum. in FT-L	Average Response Time in Seconds for Contrast Values				
		0.75	0.45	0.35	0.20	0.10
.8	2.5×10^{-3}	1.21	1.34	1.53	1.76	1.95
.8	6.0×10^{-4}	1.36	1.70	2.53	3.04	3.57
.8	1.2×10^{-4}	6.03	5.34	7.00	11.20	19.51
4.0	2.5×10^{-3}	1.45	1.64	1.89	2.36	2.61
4.0	6.0×10^{-4}	2.37	2.91	4.32	5.38	9.83
4.0	1.2×10^{-4}	14.44	17.27	18.07	26.33	31.55
10	2.5×10^{-4}	1.57	2.57	2.52	2.94	5.36
10	6.0×10^{-4}	4.13	5.78	6.24	7.44	14.81
10	1.2×10^{-4}	16.83	21.83	28.72	38.36	49.12

TABLE III
(F_3)

CONTRAST VS. AVERAGE REPONSE TIME
(5 SUBJECTS), 2.6 CYCLES/DEGREE

Preadaptation Lum. in FT-L	Ave Target Lum. in FT-L	Average Response Time in Seconds for Contrast Values				
		0.75	0.45	0.35	0.20	0.10
.8	2.5×10^{-3}	1.31	1.33	1.38	1.59	1.69
.8	6.0×10^{-4}	2.08	2.00	2.42	2.59	3.19
.8	1.2×10^{-4}	10.08	11.80	21.72	22.50	33.26
4.0	2.5×10^{-3}	1.52	1.61	1.76	1.92	2.07
4.0	6.0×10^{-4}	2.74	4.02	4.40	4.72	5.79
4.0	1.2×10^{-4}	27.00	31.91	38.13	41.69	55.04
10	2.5×10^{-3}	1.82	1.84	2.04	2.28	2.53
10	6.0×10^{-4}	4.66	4.90	5.59	7.08	9.44
10	1.2×10^{-4}	38.81	41.68	47.22	50.33	65.44

TABLE IV
(F_4)

CONTRAST VS. AVERAGE RESPONSE TIME
(5 SUBJECTS), 4.0 CYCLES/DEGREE

Preadaptation Lum. in FT-L	Ave Target Lum. in FT-L	Average Response Time in Seconds for Contrast Values				
		0.75	0.45	0.35	0.20	0.10
.8	2.5×10^{-3}	1.39	1.44	1.54	1.69	1.83
.8	6.0×10^{-4}	2.28	2.33	2.51	3.04	3.03
.8	1.2×10^{-4}	25.52	30.37	33.10	41.61	51.57
4.0	2.5×10^{-3}	1.69	1.61	1.77	1.82	2.06
4.0	6.0×10^{-4}	3.78	3.66	4.01	4.82	5.71
4.0	1.2×10^{-4}	48.36	52.56	63.56	66.35	77.69
10	2.5×10^{-3}	1.91	1.83	2.01	2.17	2.48
10	6.0×10^{-4}	5.31	5.77	6.83	8.24	12.30
10	1.2×10^{-4}	69.63	73.69	74.93	86.19	96.41

TABLE V
(F_5)

CONTRAST VS. AVERAGE RESPONSE TIME
(5 SUBJECTS), 5.6 CYCLES/DEGREE

Preadaptation Lum. in FT-L	Ave Target Lum. in FT-L	Average Response Time in Seconds for Contrast Values				
		0.75	0.45	0.35	0.20	0.10
.8	2.5×10^{-3}	1.31	1.42	1.58	1.76	1.91
.8	6.0×10^{-4}	2.85	4.13	6.07	7.07	8.52
.8	2.5×10^{-4}	17.62	30.89	38.36	46.92	--
4.0	2.5×10^{-3}	1.53	1.93	2.12	2.46	2.20
4.0	6.0×10^{-4}	6.24	7.25	13.23	16.10	21.25
4.0	2.5×10^{-4}	31.20	52.22	67.15	73.31	--
10	2.5×10^{-3}	1.98	2.35	2.87	3.23	3.94
10	6.0×10^{-4}	11.56	14.60	19.03	23.43	30.81
10	2.5×10^{-4}	66.13	88.78	98.48	116.18	--

Table VI
Target Size = 15^{o}
(c_1 = 0.75

AVERAGE RESPONSE TIME VS. FREQUENCY AT CONTRAST 0.75 (S=5)

L = Preadaptation Luminance
(L_1 0.8 ft.L, L_2 = 4.0 ft.L, L_3 = 10.0 ft.L)

T = Target Luminance
(T_1 = 0.0025 ft.L, T_2 = 0.0006 ft.L, T_3 = 0.00012 ft.L)

Frequency in Cycles Per Degree	Average Response Time in Seconds for								
	L_1T_1	L_1T_2	L_1T_3	L_2T_1	L_2T_2	L_2T_3	L_3T_1	L_3T_2	L_3T_3
0.4 c/d	1.55	3.33	10.81	1.88	5.64	12.16	2.40	6.87	19.16
1.0 c/d	1.21	1.36	6.03	1.45	2.37	14.44	1.57	4.13	16.83
2.6 c/d	1.31	2.08	10.08	1.52	3.74	27.00	1.82	4.66	38.81
4.0 c/d	1.39	2.28	25.52	1.69	3.78	48.36	1.91	5.31	69.63
5.6 c/d	1.31	2.85	--	1.53	6.24	--	1.98	11.56	--
10.0 c/d	1.68	--	--	3.39	--	--	5.69	--	--

TABLE VII
Targe Size = 15^{o}
(c_2 = 0.45)

AVERAGE RESPONSE TIME VS. FREQUENCY AT CONTRAST (S=5)

L = Preadaptation Luminance
(L_1 = 0.8 ft.L, L_2 = 4.0 ft.L, L_3 = 10.0 ft.L)

T = Target Luminance
(T_1 = 0.0025 ft.L, T_2 = 0.0006 ft.L, T_3 = 0.00012 ft.L)

Frequency in Cycles Per Degree	Average Response Time in Seconds for								
	L_1T_1	L_1T_2	L_1T_3	L_2T_1	L_2T_2	L_2T_3	L_3T_1	L_3T_2	L_3T_3
0.4 c/d	1.88	5.04	10.49	2.65	7.54	19.57	3.82	8.83	24.42
1.0 c/d	1.34	1.70	5.34	1.64	2.91	17.27	2.57	5.78	21.83
2.6 c/d	1.33	2.00	11.80	1.61	4.02	31.91	1.84	4.90	41.68
4.0 c/d	1.44	2.33	30.37	1.69	3.78	48.36	1.83	5.77	73.69
5.6 c/d	1.42	4.13	--	1.93	7.25	--	2.35	14.60	--
10.0 c/d	1.66	--	--	3.33	--	--	7.06	--	--

Table VIII
Target Size = 15^{o}
(c_3 = 0.35)

AVERAGE RESPONSE TIME VS. FREQUENCY AT CONTRAST = 0.35 (S=5)

L = Preadaptation Luminance
(L_1 = 0.8 ft.L, L_2 = 4.0 ft.L, L_3 = 10.0 ft.L)

T = Target Luminance
(T_1 = 0.0025 ft.L, T_2 = 0.0006 ft.L, T_3 = 0.00012, ft.L)

Frequency in Cycles Per Degree	Average Response Time in Seconds for								
	L_1T_1	L_1T_2	L_1T_3	L_2T_1	L_2T_2	L_2T_3	L_3T_1	L_3T_2	L_3T_3
0.4 c/d	2.54	6.37	14.25	3.96	9.77	24.12	5.21	11.25	33.82
1.0 c/d	1.53	2.53	7.00	1.89	4.32	18.07	2.52	6.24	28.72
2.6 c/d	1.38	2.42	21.72	1.76	4.40	38.13	2.04	5.59	47.22
4.0 c/d	1.54	2.51	33.10	1.77	4.01	63.56	2.01	6.83	74.93
5.6 c/d	1.58	6.07	--	2.12	13.23	--	2.87	19.03	--
10.0 c/d	2.32	--	--	3.54	--	--	8.18	--	--

Table IX
Target Size = 15°
(c_4 = 0.20)

AVERAGE RESPONSE TIME VS. FREQUENCY AT CONTRAST = 0.20 (S=5)

L = Preadaptation Luminance
(L_1 = 0.8 ft.L, L_2 = 4.0 ft.L, L_3 = 10.0 ft.L)

T = Target Luminance
(T_1 = 0.0025 ft.L, T_2 = 0.0006 ft.L, T_3 = 0.00012 ft.L)

Frequency in Cycles Per Degree	Average Response Time in Seconds for								
	L_1T_1	L_1T_2	L_1T_3	L_2T_1	L_2T_2	L_2T_3	L_3T_1	L_3T_2	L_3T_3
0.4 c/d	3.25	8.07	18.56	6.13	13.03	34.71	7.00	15.69	46.60
1.0 c/d	1.76	3.04	11.20	2.36	5.38	26.33	2.94	7.44	38.36
2.6 c/d	1.59	2.59	22.50	1.92	4.72	41.69	2.28	7.08	50.33
4.0 c/d	1.69	3.04	41.61	1.82	4.82	66.35	2.17	8.24	86.19
5.6 c/d	1.76	7.07	--	2.46	16.10	--	3.23	23.43	--
10.0 c/d	2.39	--	--	4.17	--	--	14.83	--	--

Table X
Target Size = 15^{o}
(c_5 = 0.10)

AVERAGE RESPONSE TIME VS. FREQUENCY AT CONTRAST = 0.10 (S=5)

L = Preadaptation Luminance
(L_1 0.8 ft.L, L_2 = 4.0 ft.L, L_3 = 10.0 ft.L)

T = Target Luminance
(T_1 = 0.0025 ft.L, T_2 = 0.0006 ft.L, T_3 = 0.00012 ft.L)

Frequency in Cycles Per Degree	Average Response Time in Seconds for								
	L_1T_1	L_1T_2	L_1T_3	L_2T_1	L_2T_2	L_2T_3	L_3T_1	L_3T_2	L_3T_3
0.4 c/d	5.65	12.78	21.33	9.91	15.47	47.35	9.55	21.01	61.37
1.0 c/d	1.95	3.57	19.51	2.61	9.83	31.55	5.36	14.81	49.12
2.6 c/d	1.69	3.19	33.26	2.07	5.79	55.04	2.53	9.44	65.44
4.0 c/d	1.83	3.03	51.57	2.06	5.71	77.69	2.48	12.30	96.41
5.6 c/d	1.91	8.62	--	2.20	21.26	--	3.94	30.81	--
10.0 c/d	4.41	--	--	8.59	--	--	16.21	--	--

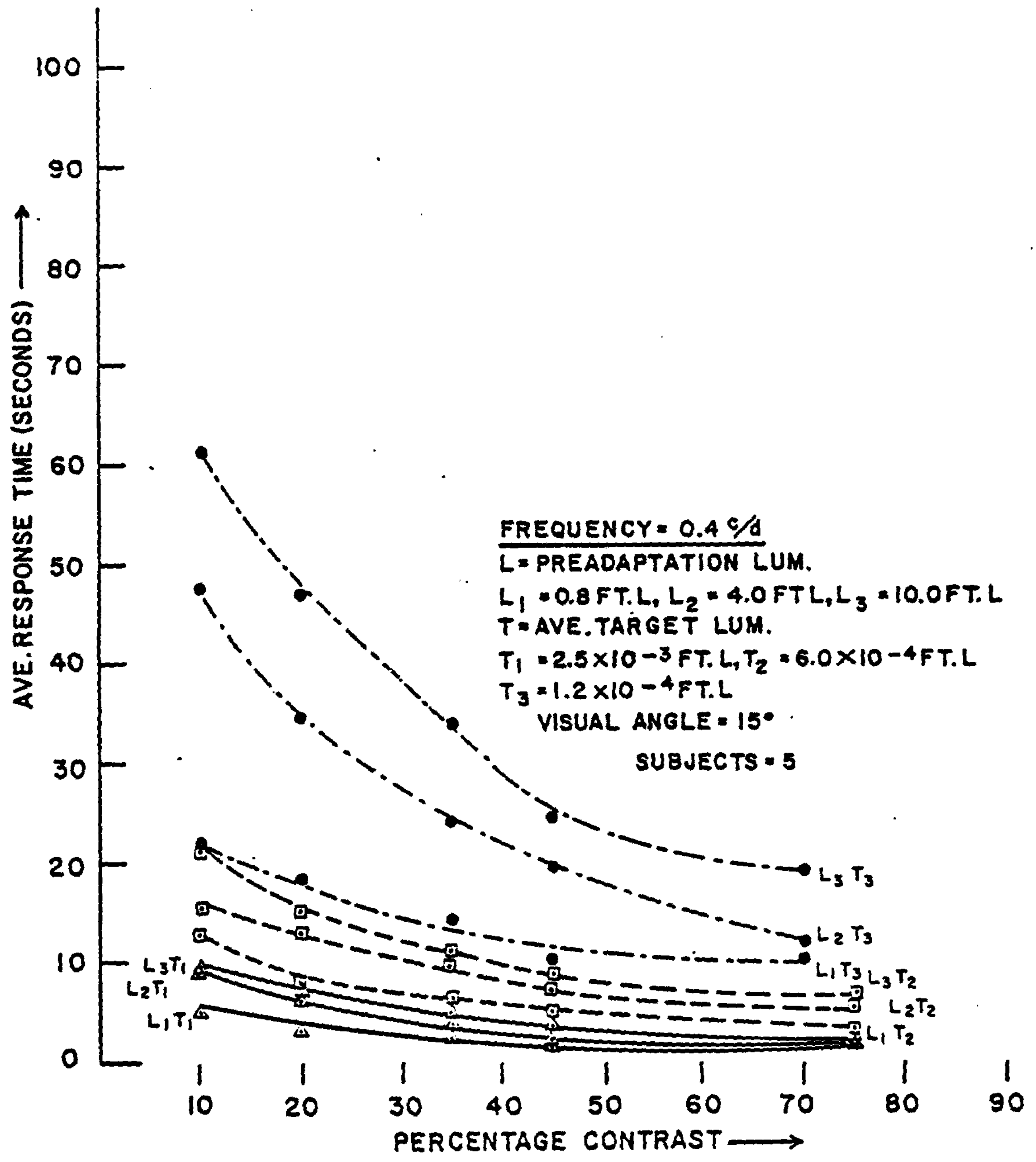

Figure 4. Average response time vs. target contrast for spatial frequency of 0.4 c/d for three preadaptation fields X three average target luminance levels.

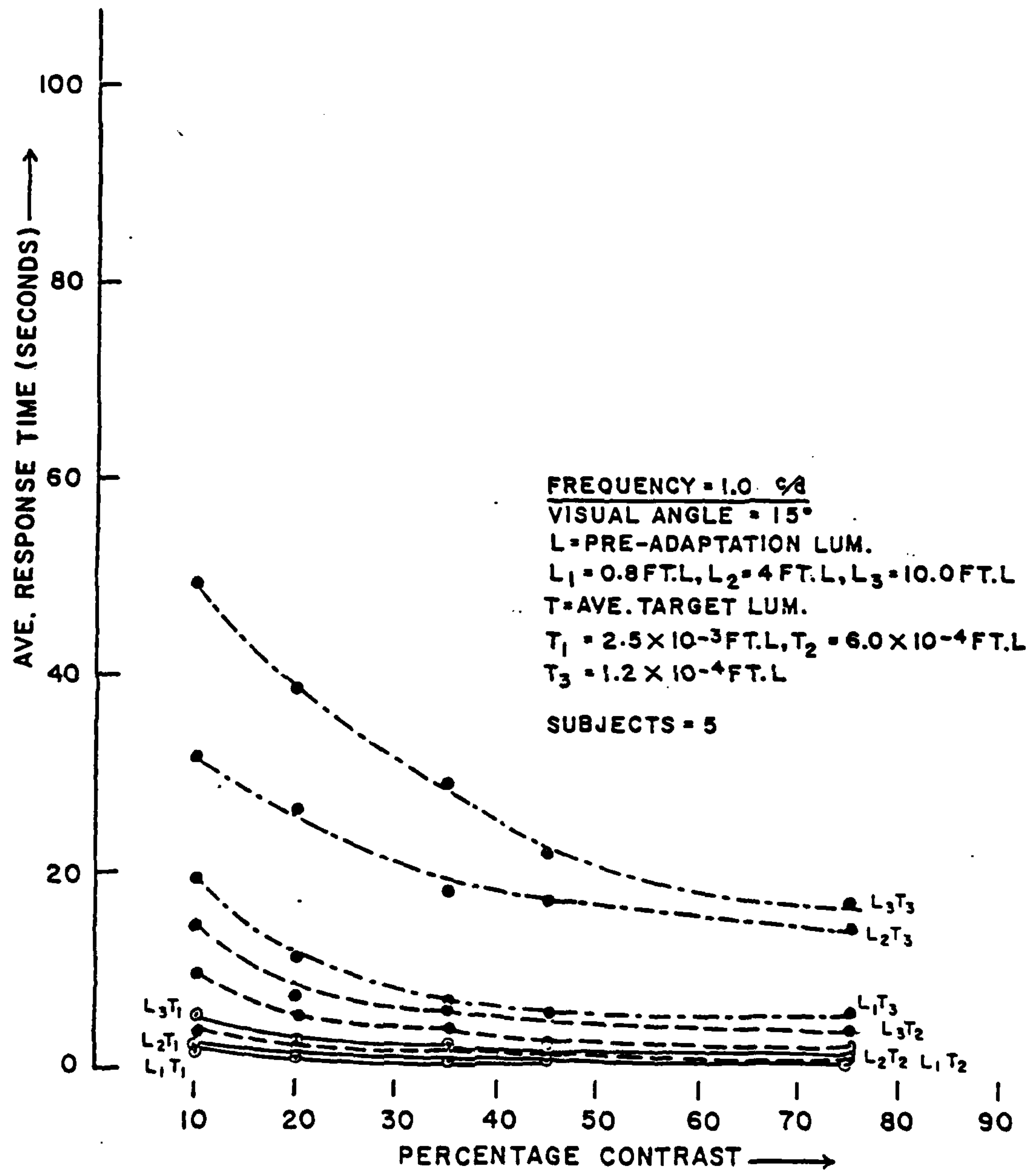

Figure 5. Average response time vs. target contrast for spatial frequency of 1.0 c/d for three preadaptation fields X three average target luminance levels.

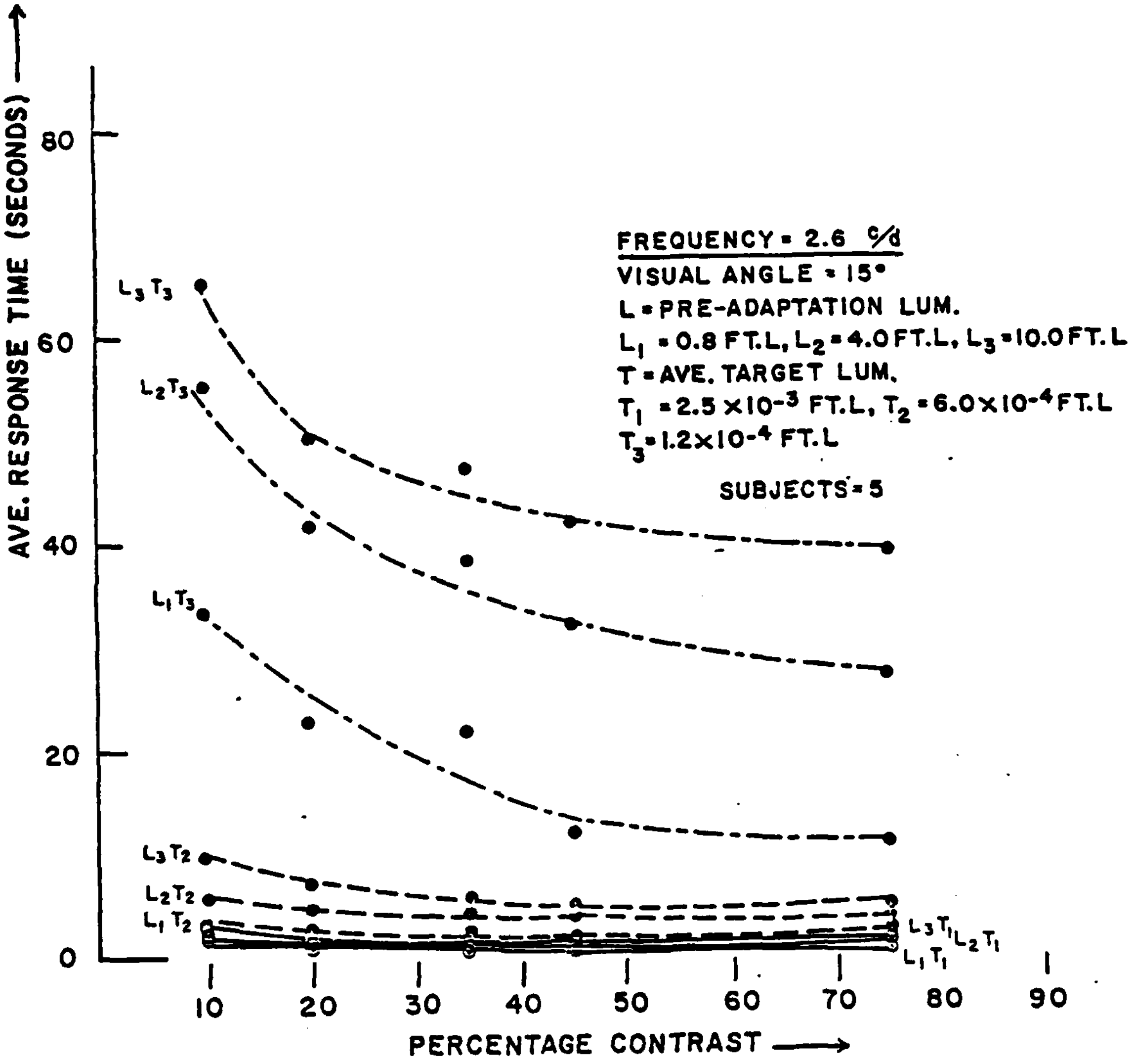

Figure 6. Average response time vs. target contrast for spatial frequency of 2.6 c/d for three preadaptation fields X three average target luminance levels.

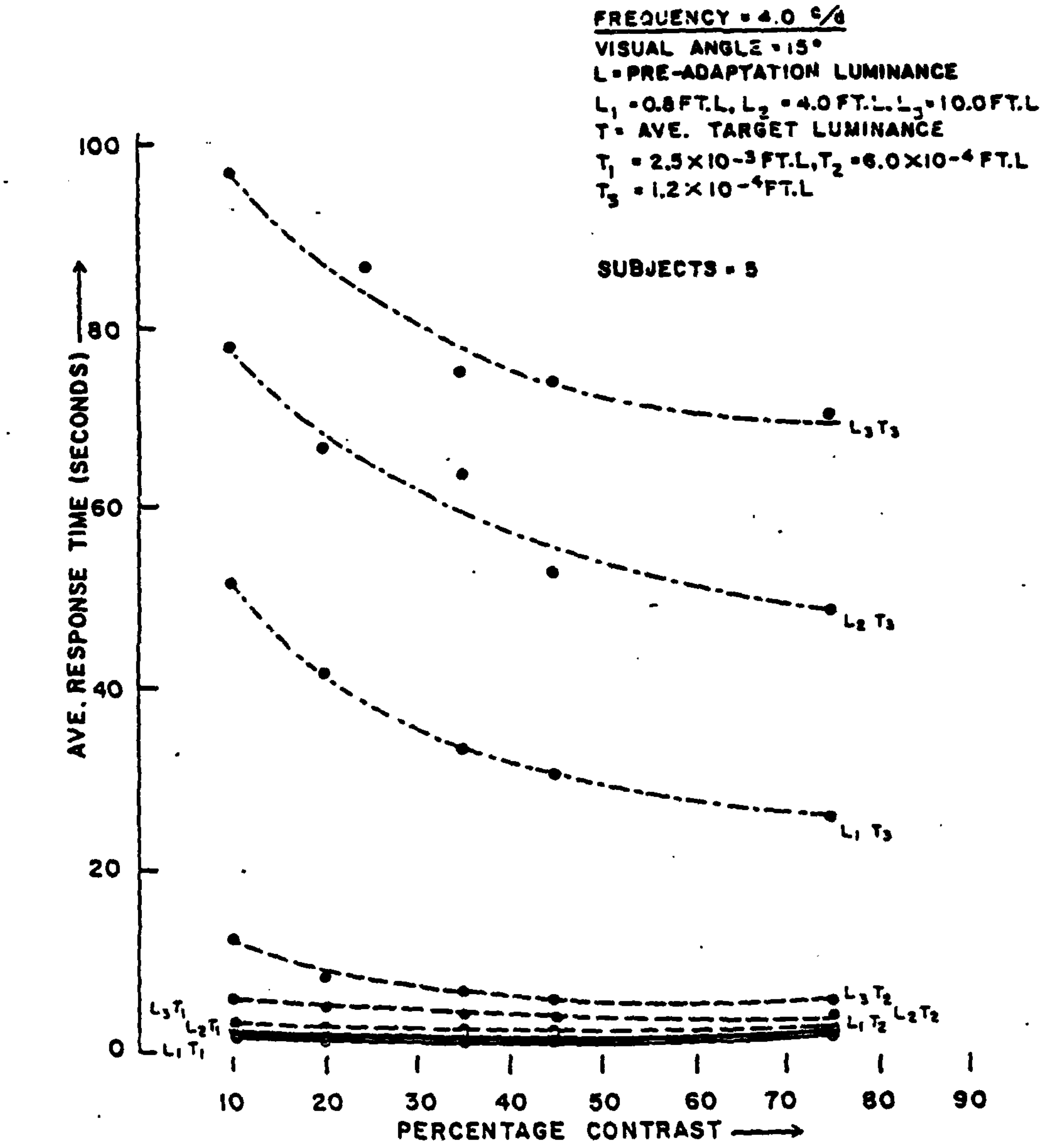

Figure 7. Average response time vs. target contrast for spatial frequency of 4.0 c/d for three preadaptation fields X three average target luminance levels.

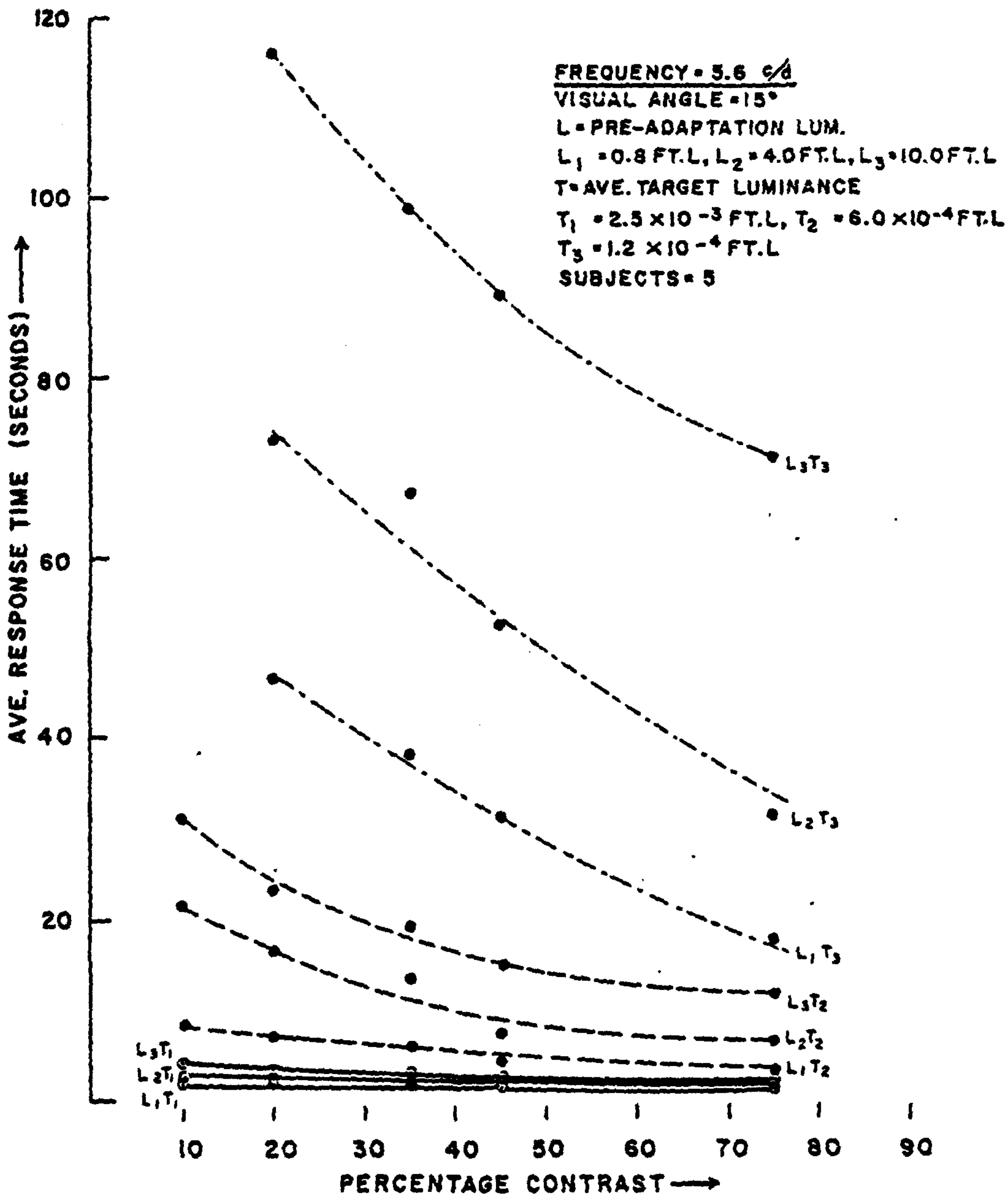

Figure 8. Average response time vs. target contrast for spatial frequency of 5.6 c/d for three preadaptation fields X three average target luminance levels.

Speros-Mitra 30

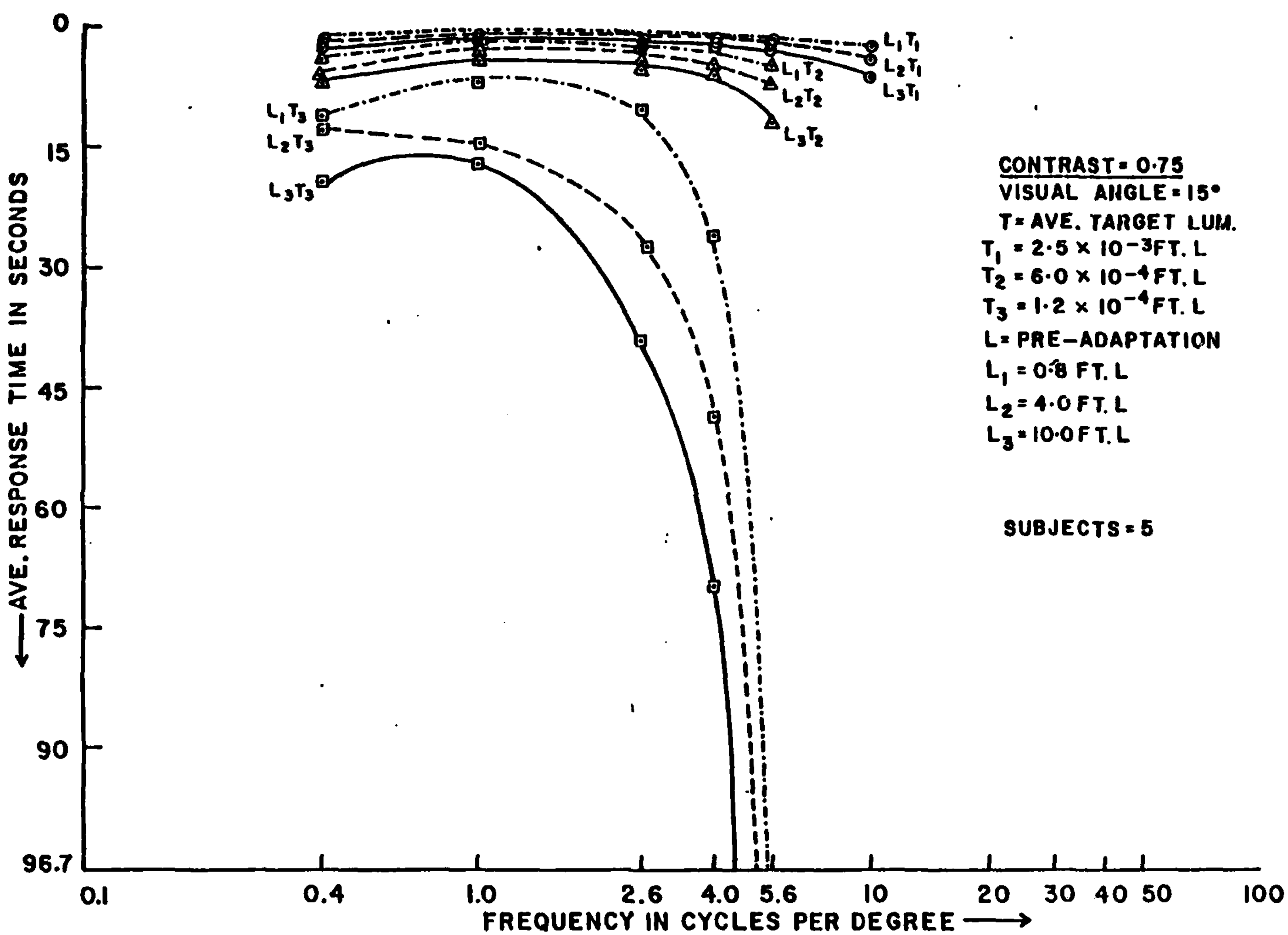

Figure 9. Average response time vs. spatial frequency at 0.75 contrast for three preadaptation fields X three average target luminance levels.

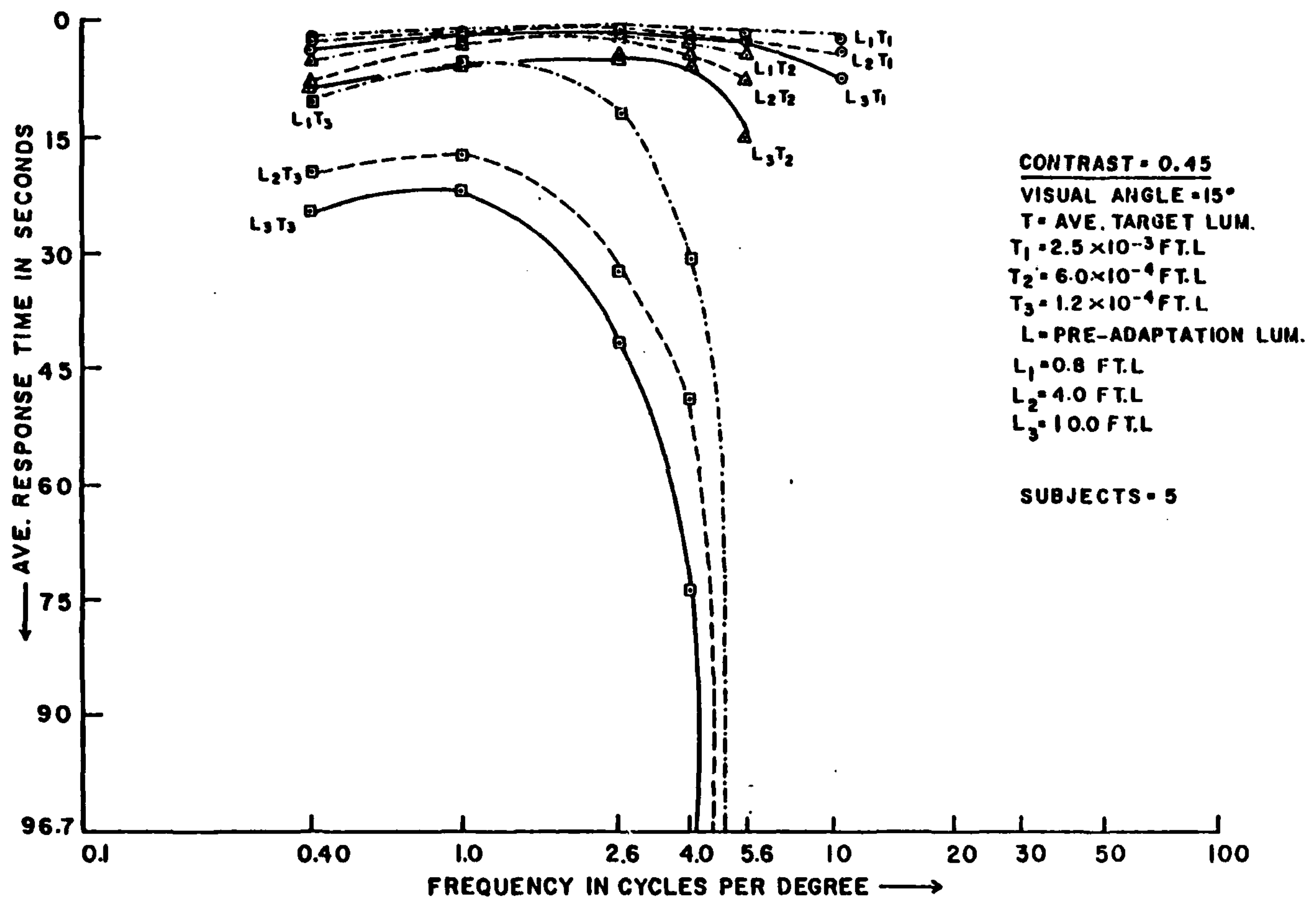

Figure 10. Average response time vs. spatial frequency at 0.45 contrast for three preadaptation fields X three average target luminance levels.

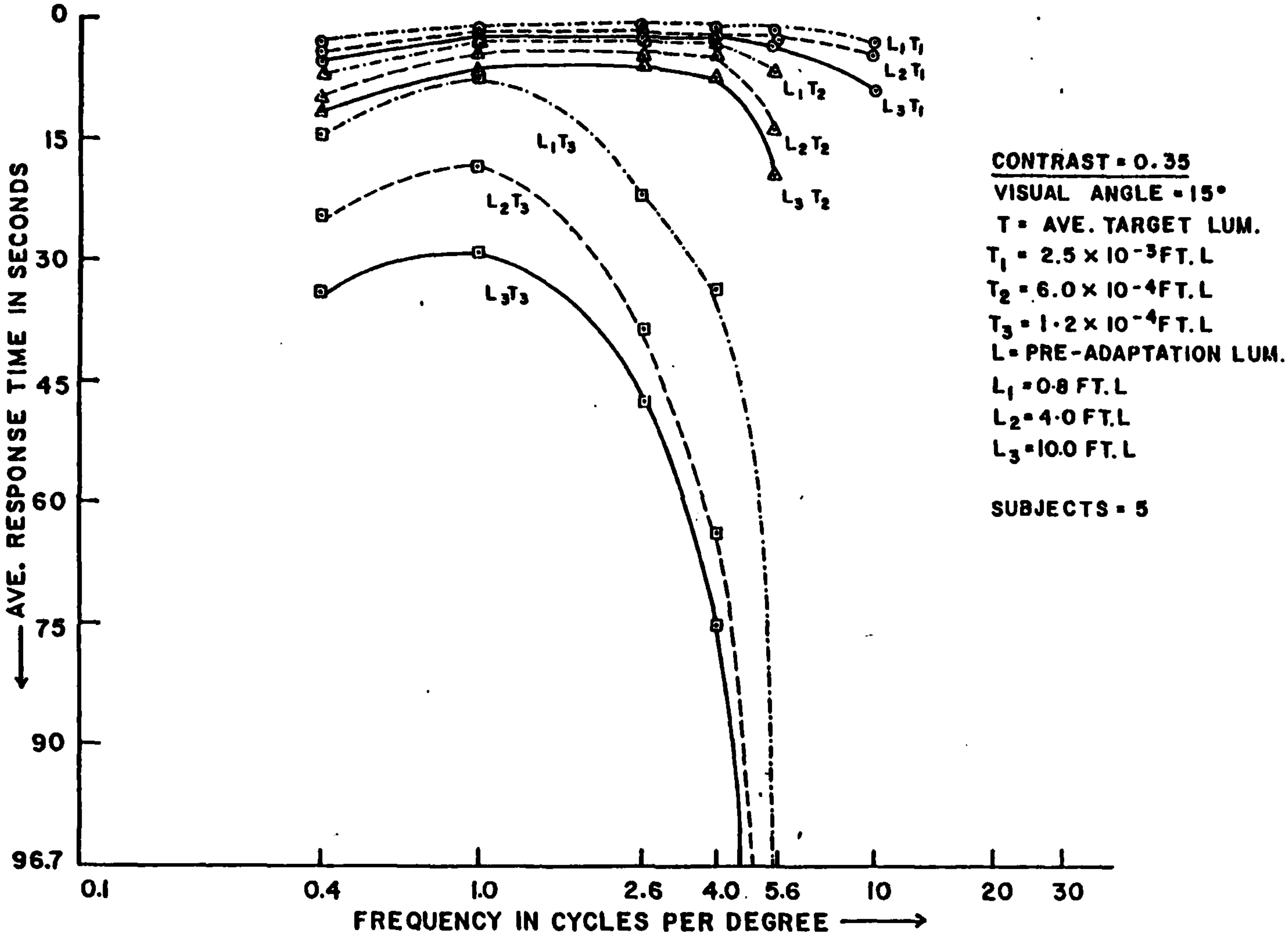

Figure 11. Average response time vs. spatial frequency at 0.35 contrast for three preadaptation fields X three average target luminance levels.

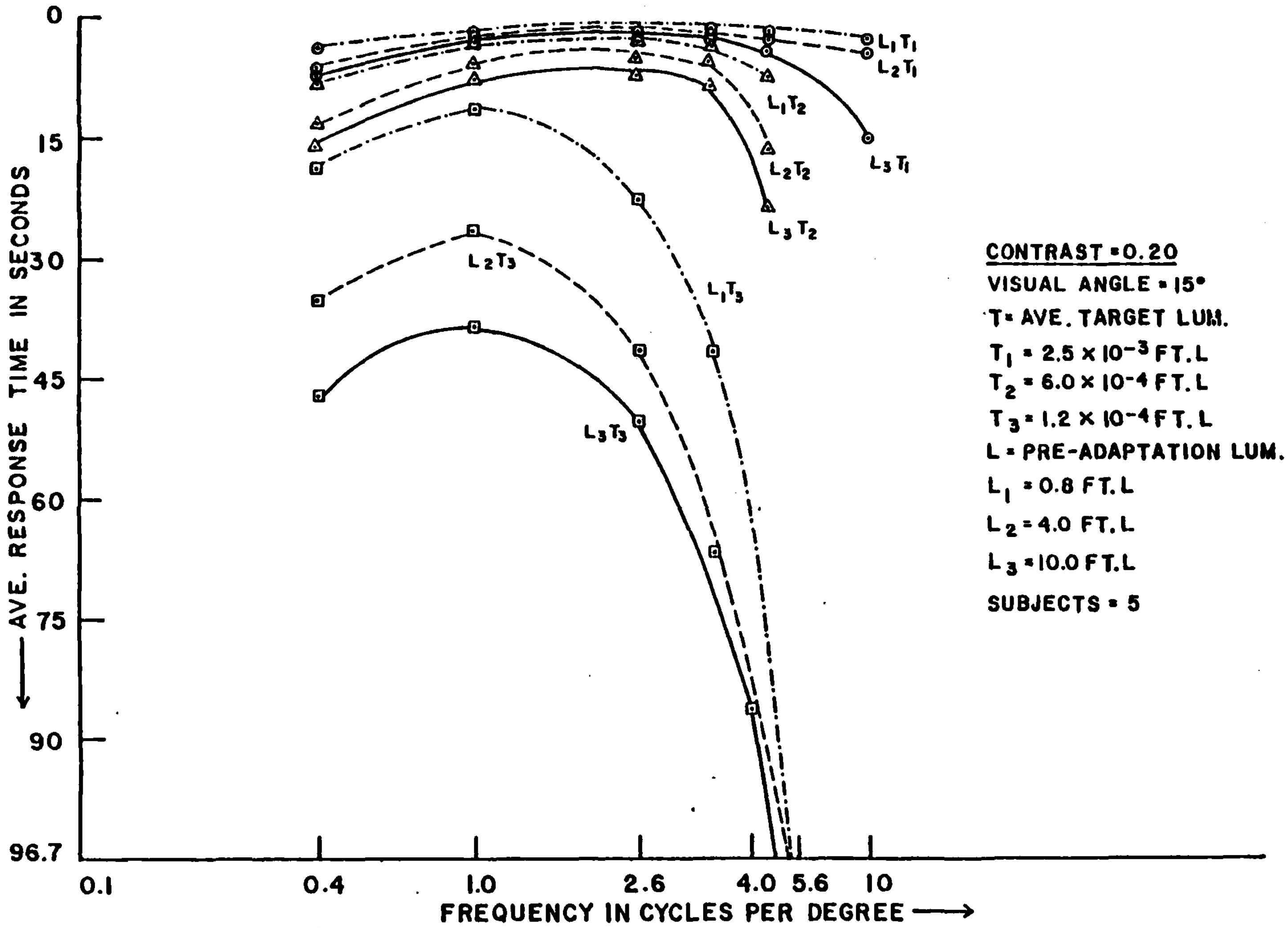

Figure 12. Average response time vs. spatial frequency at 0.20 contrast for three preadaptation fields X three average target luminance levels.

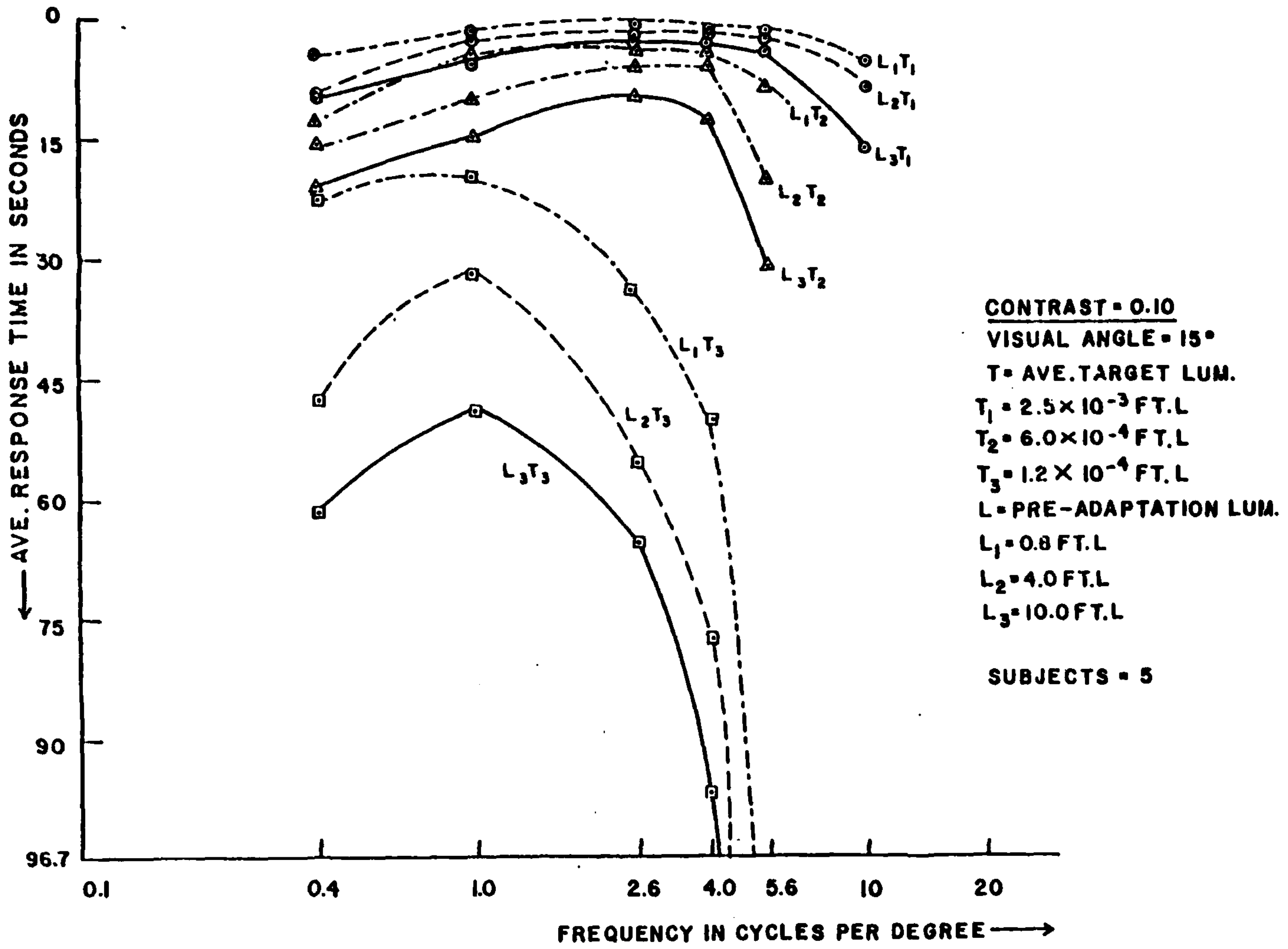

Figure 13. Average response time vs. spatial frequency at 0.10 contrast for three preadaptation fields X three average target luminance levels.

Discussion

The data taken with a target of 15° visual angle indicate quite clearly that the temporal contrast sensitivity functions describe the capability of a user of optical image intensifier to detect and discriminate a visual scene under different night-viewing conditions in the event of failure of the optical device.

At present we are taking data with a small target of visual angle 2° 30' for the frequencies used in the first set under the same conditions. Though the second set of data collection is not complete yet, the data already taken indicates very clearly that further and more drastic degradation in recovery time results with the reduction in target size even for the highest target luminance (2.5×10^{-3} ft-L) level.

We intend to repeat the experiment for at least one more target size (probably of visual angle 7° 30') so that with the help of the data obtained at three different visual angles we can extrapolate and generalize the effect of chromatic adaptation on recovery time to any given visual angle i.e., for any stimulus size in a complex visual scene.

Hagermans and Wildt (1979) recently found that the relationship between the width of the stimulus at which no further increase in sensitivity occurs and the spatial frequency in the normal observer is linear. They state that for a spatial frequency of 10 cycles/degree and a target luminance of 3 ft-L maximum sensitivity is attained at around 1° of visual angle. Furthermore, our data indicate that at a scotopic luminance level of 2.5×10^{-3} ft-L maximum sensitivity is obtained at a stimulus size of about 7° 30' for a 10 cycles/degree spatial frequency. At a stimulus size of 2° 30' the sine-wave grating of 10 c/d is just rarely visible. Therefore the luminance level particularly in the scotopic range has a tremendous effect on the stimulus width at which the maximum sensitivity is attained for a particular frequency. This effect is quite expected since at photopic level the fovea is responsible for detecting test fields of high frequency whereas in the scotopic range, more of peripheral region might play an important role.

To our knowledge, the relationship between stimulus width and spatial frequency at scotopic levels has not been established as yet particularly the stimulus size of maximum contrast sensitivity at various spatial frequencies is not known. This knowledge will not only help in designing optical devices for detecting finer details but will be of great significance in assessment of neural visual system.

References

1. Cavonius, C.R. and Hilz, R.: Invariance of visual receptive-field size and visual acuity with viewing distance. J. Optical Soc. Amer. 63:929-933, 1973.

2. Campbell, F.W. and Green, D.G.: Optical and retinal factors affecting visual resolution. J. Physiol. 181:576-593, 1965.

3. Campbell, F.W.: The human eye as an optical filter. Proc of IEEE 56:1009-1014, 1968.

4. Campbell, F.W. and Robson, J.G.: Application of Fourier analysis to the visibility of gratings. J. Physiol. 197:551-566, 1968.

5. Chiou, W.C.: Utilization of existing aricraft landing light as an artificial illumination source for AN/PVS-5 night vision goggles training. USAARL Report No. 1-7-1, October 1976. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

6. Glick, D.D. and Moser, C.E.: After images associated with using the AN/PVS-5 night vision goggle. USAARL Report No. 75-1-7-1, August 1974. U.S Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

7. Glick, D.D. and Wiley, R.W.: A visual comparison of standard and experimental maps using the AN/PVS-5 night vision goggle. USAARL Report No. 75-26-7-6, March 1975. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

8. Glick, D.D., Wiley, R.W., Moser, C.E., and Chun, K.P.: Dark adaptation changes associated with use of the AN/PVS-5 night vision goggle. USAARL Report no. 72-2-7-2, August 1974. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

9. Hagemans, K.H. and v.d. Wildt, G.J.: The influence of the stimulus width on the contrast sensitivity function in amblyopia. Invest. Ophthalmol. 18:842-847, 1979.

10. Hirsch, M.J. and Weymouth, F.W.: Distance discrimination. I. Theoretic considerations. Arch. Ophthal. 39:210-223, 1948.

11. Hirsch, M.J. and Weymouth, F.W.: Distance Discrimination. V. Effect of motion and distance targets on monocular and binocular distance discriminating. J. of Aviat. Med. 18:594-600, 1947.

12. Howell, E.R. and Hess, R.F.: The functional area for summation to threshold for sinusoidal gratings. Vision Res. 18:369-374, 1978.

13. Lees, M.A., Glick, D.D., Kimball, K.A., and Snow, A.C.: In-flight performance with night vision goggles during reduced illumination. USAARL Report No. 76-27, August 1976. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

14. Lees, M.A., Kimball, K.A., Hoffman, M.A., and Stone, L.W.: Aviator performance during day and night terrain flight. USAARL Report No. 77-3, December, 1976. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

15. Lewis, C.E., Blakely, W.R., Swarsop, R., Masters, R.L., and McMurty, T.C.: Landing performance by low-time private pilot after sudden loss of binocular vision. Cyclops II. Aerospace Medicine 44:1241-1245, 1973.

16. Lewis, C.E. and Krier, G.E.: Flight Research Program XVI: Landing Performance in jet aircraft after the loss of binocular vision. Aerospace Medicine 40:9-11, 1969.

17. van Meeretern, A. and Boogaard, J.: Visual contrast sensitivity with ideal image intensifiers. OPTIK 31:179-191, 1973.

18. van Meeretern, A. and Vos, J.J.: Resolution and contrast sensitivity at low luminance. Vision Research 12:825-833, 1972.

19. van Ness, F.L. and Bouman, M.A.: Spatial Modulation transfer in the human eye. J. of Optical Soc. of Amer. 57:401--406, 1967.

20. Sanders, M.G., Kimball, K.A., Frezell, L.L. and Hofmann, M.A.: Aviator performance measurement during low altitude rotary using flight with the AN/PVS-5 night vision goggles. USAARL Report No. 76-10, December 1975. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

21. Sanders, M.D., Kimball, K.A., Frezell, T.L., and Hofmann, M.A.: Helicopter flight performance with the AN/PVS-5 night vision goggles. Paper presented at the Aerospace Medical panel meeting, AGARD/NATO, October, 1975, Ankara, Turkey.

22. Sloan, L.L. and Attman, A.: Factors involved in several tests of binocular depth perception. Arch. Ophthal. 52:524-544, 1954.

23. Teichner, W.H., Kobrick, J.L., and Dusek, E.R.: Commonplace viewing and depth discrimination. J. of Optic at Soc of Amer. 45:913-920, 1955.

24. Teichner, W.H., Kobrick, J.L., and Wehrkamp, R.F.: Effects of terrain and observation distance on depth discrimination Environmental Protection Division, U.S. Army Quartermaster Research and Development Center, Natick, Massachusetts, Report No. 228, May 1954.

25. Teichner, W.H., Kobrick, J.L., and Wehrkamp, R.F.: The effects of terrain and observation distance on relative depth discrimination. Amer. J. of Psych. 68:193-208, 1955.

26. Wiley, R.W., Glick, D.D., Buch, C.F., and Park, C.K.: Depth perception with the AN/PVS-5 night vision goggle USAARL Report No. 76-25, July 1976. U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.

27. Wiley, R.W. and Holly, F.F.: Vision with the AN/PVS-5 night vision goggle. Paper presented at the Aerospace Medical Panel meeting AGARD/NATO, Nevilly Sue Seine, France, 1976.

Legends

Tables

Table I Contrast sensitivity vs. angerage reponse time of 5 subjects at a frequency of 0.4 cycles/degree.

Table II Contrast sensitivity vs. average response time of 5 subjects at a frequency of 1.0 cycles/degree.

Table III Contrast sensivity vs. average response time of 5 subjects at a frequency of 2.6 cycles/degree.

Table IV Contrast sensivitity vs. average response time of 5 subjects at a frequency of 4.0 cycles/degree.

Table V Contrast sensivitity vs. average response time of 5 subjects at a frequency of 5.6 cycles/degree.

Table VI Average response time vs. frequency of 5 subjects at contrast of 0.75.

Table VII Average response time vs. frequency of 5 subjects at contrast 0.45.

Table VIII Average response time vs. frequency of 5 subjects at contrast of 0.35.

Table IX Average response time vs. frequency of 5 subjects at contrast of 0.20.

Table X Average response time vs. frequency of 5 subjects at a contrast of 0.10.

Figures

Figure 1 Schematic diagram of the experimental set up for sine-wave presentation.

Figure 2 Schematic diagram showing the experimental set up for the target and pre-adaptation fields.

Figure 3 Spectral Power Distribution of (a) AN/PVS-5 Image-intensifier and (b) the combination of colored glass filters simulating the chromaticity of Image-intensifiers used in the preadaptation light source.

Figure 4 Average response time vs. target contrast for spatial frequency of 0.4 c/d for three preadaptation fields X three average target luminance levels.

Figure 5 Average response time vs. target contrast for spatial frequency of 1.0 c/d for three preadaptation fields X three average target luminance levels.

Figure 6 Average response time vs. target contrast for spatial frequency of 2.6 c/d for three preadaptation fields X three average target luminance levels.

Figure 7 Average response time vs. target contrast for spatial frequency of 4.0 c/d for three preadaptation fields X three average target luminance levels.

Figure 8 Average response time vs. target contrast for spatial frequency of 5.6 c/d for three preadaptation fields X three average target luminance levels.

Figure 9 Average response time vs. spatial frequency at 0.75 contrast for three preadaptation fields X three average target luminance levels.

Figure 10 Average response time vs. spatial frequency at 0.45 contrast for three preadaptation fields X three average target luminance levels.

Figure 11 Average response time vs. spatial frequency at 0.35 for three preadaptation fields X three average target luminance levels.

Figure 12 Average response time vs. spatial frequency at 0.20 contrast for three preadaptation fields X three average target luminance levels.

Figure 13 Average response time vs. spatial frequency at 0.10 contrast for three preadaptation fields X three average target luminance levels.

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